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INVESTIGATION OF AN ALUMINUM ROLLING HELIX CRASH ENERGY ABSORBER

ARA, Inc.
2017 W. Garvey Avenue
West Covina, Calif. 91790

May 1977

Final Report for Period February 1975 - December 1975

Approved for public release;
distribution unlimited.

Prepared for

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
Fort Eustis, Va. 23604

EUSTIS DIRECTORATE POSITION STATEMENT

This report was prepared by Aerospace Research Associates (ARA), Inc., under the terms of Contract DAAJ02-75-C-0015. The objective of this effort was to determine the feasibility of using a lightweight energy absorber of the rolling helix type as a crash energy absorbing leg for crashworthy helicopter troop seat designs.

This report has been reviewed by the Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, and is considered to be technically sound.

This program was conducted under the technical management of Mr. George T. Singley, III, Technology Applications Division.

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This report covers an investigation of various aluminum alloy wires suitable for a rolling helix energy absorber strut (TOR-SHOK) for use in crashworthy troop seats. Several aluminum alloy wire types were investigated to determine the linear stroking distance that the device could endure prior to the breaking of the helical wires, and to ascertain compatibility with the 6061-T6 aluminum tubes that are used as the struts to transmit the impact forces into the energy-absorbing helical wires. →(cont on p 2)

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20. Abstract (Cont'd) fr p 1473B)

Once the wire was selected, several struts were fabricated and tested. In addition, two (2) units were subjected to environmental tests, in accordance with Military Standard 810B, and were statically tested after the environmental tests. This study indicated that the most compatible aluminum wire to be used with the 6061-T6 aluminum tubing is the 5056-H38 series aluminum wire. The devices, after being subjected to the environmental tests as dictated by Military Standard 810B, performed the same as those devices that were not subjected to the environmental tests. This was primarily a result of properly anodizing and sealing the aluminum tubing.

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INTRODUCTION

The use of energy-absorbing strut-like devices to absorb energy for such applications as troop or passenger seats in helicopters or light fixed-wing aircraft is well known. For such types of seats, the stroking loads in the struts are relatively low (approximately 1000 to 1500 pounds) when compared to armored crew seats, since the weight of the seat is insignificant when compared to the occupant's weight. On this basis, the strut-like energy-absorbing devices can be fabricated from readily available aluminum tubing, such as 6061-T6. One type of cyclic strain device which ARA, Inc. has developed and applied successfully to many shock load applications is an energy-absorbing rolling helix called the TOR-SHOK. This device, when used with the aluminum tubing, offers significant weight savings when compared to conventional high-strength steel tubing and wires which are used for crashworthy armored crew seats.

The purpose of this study was to determine the feasibility of a lightweight aluminum rolling helix strut. Struts were fabricated and tested. The test results demonstrated that aluminum struts operated satisfactorily, even after exposure to an environment specified by Military Standard 810B. The description of the aluminum wire selection testing and an evaluation of the struts are provided in the next sections.

BRIEF REVIEW OF IMPACT ATTENUATOR DEVICES

Most impact devices or energy attenuators are commonly one-time devices such as fragmenting tubes, crushable materials, and deformable structures. All of these devices use the energy that is available from unidirectional straining of the material, which usually occurs at localized portions of the material. If the same material can be cyclically strained to failure, much larger energy levels of absorption are available. An example of the comparison of specific energy absorption for unidirectional and cyclic strain to failure is shown in Figure 1. Specific Energy Absorption (SEA, which is measured in foot pounds of energy absorbed per pound of device weight) is a common parameter for comparing impact-type energy absorbers. As shown in Figure 1, when the material is repeatedly stressed slightly beyond its yield point and back, including stress in the opposite direction, the cycle may be repeated many times before failure. Empirically, for N cycles, the specific energy absorption, SEA is approximately $\sqrt{N}$ x SEA for unidirectional straining to failure.

Using only the working elements of various impact devices, a comparison of the energy-absorption capability of various devices for crashworthiness is shown in Figure 2.[1] This figure clearly demonstrates the increased capability of the cyclic straining devices over the other devices which make use of the unidirectional straining to failure. The final SEA value depends on the additional structure necessary to transmit the forces from the working elements. Since these external

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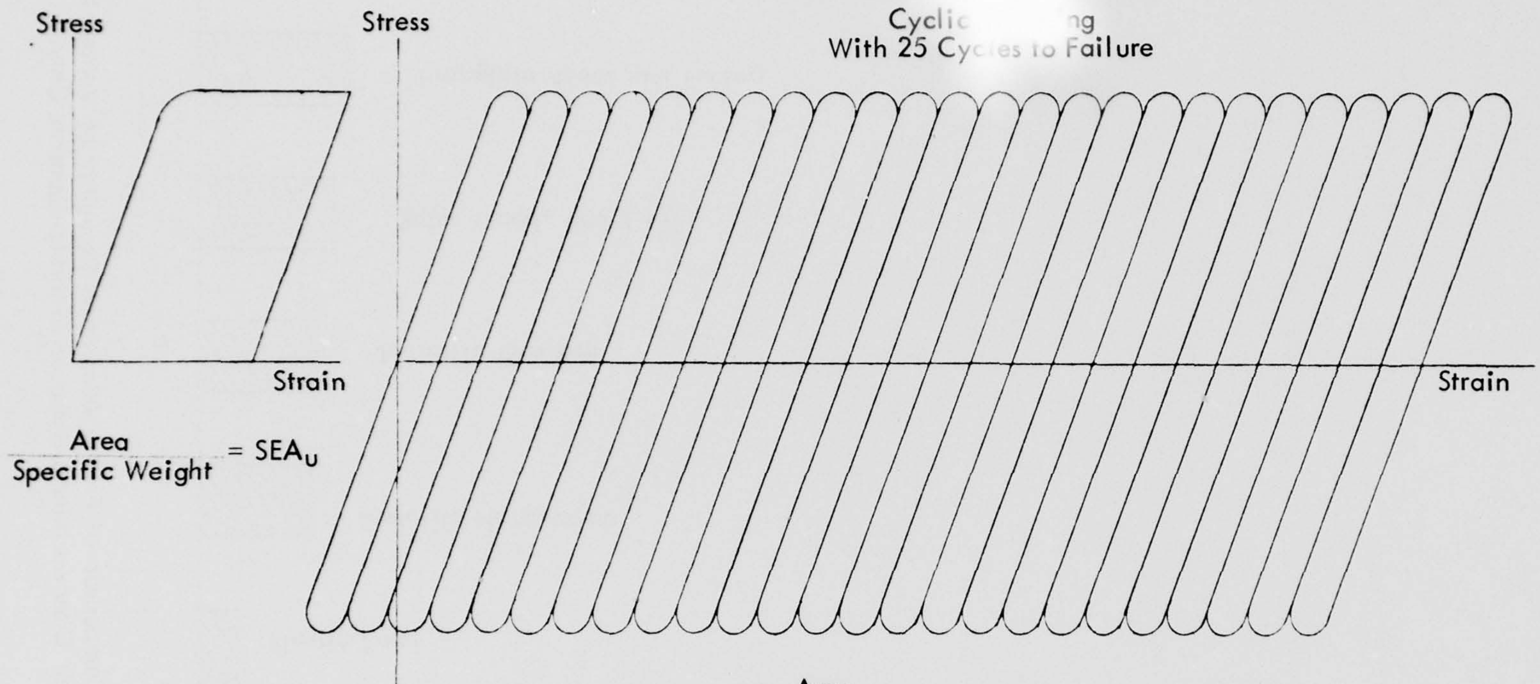
1 E. W. Schrader, Torus Absorbs Impact Energy, Design News, Volume 20, Number 23, November 10, 1965.



$$\frac{\text{Area}}{\text{Specific Weight}} = SEA_u$$

$$SEA_c = \frac{\text{Area}}{\text{Specific Weight}} = 5\ SEA_u$$

Figure 1. Comparison of Specific Energy Absorption for Unidirectional (SEA_u) and Cyclic (SEA_c) Straining to Failure.

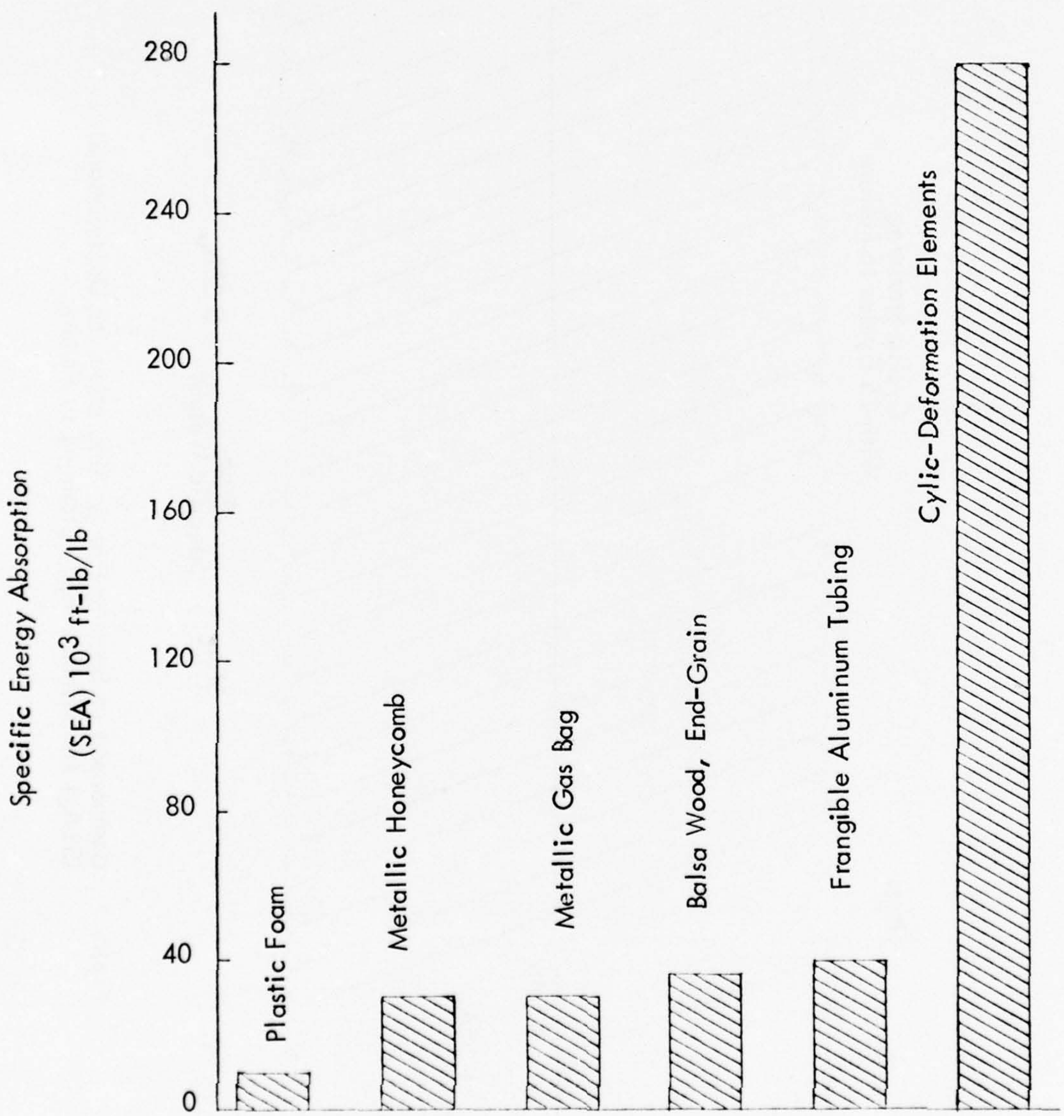


Figure 2. Comparison of Energy Absorption Capability of Various Devices for Crashworthiness Based on Working Elements Only.

mechanisms may vary widely among different devices, as well as for a given device, depending on the particular structural requirements, a meaningful comparison is difficult to establish. However, by manipulation of the working elements in relation to the surrounding structural components, very efficient cyclic straining devices can be manufactured. One type of cyclic strain device which ARA, Inc. has developed and applied successfully to many shock load applications is the rolling helix. A brief description of this device is provided as follows:

The rolling helix is designed to attenuate motion and forces in a linear direction through the use of a strut-like device. The attenuator consists of a helical coil of metal wire located between two cylinders. Each toroidal element in the coil starts to roll when impact occurs, which causes cyclic tension-to-compression plastic deformation stresses in the outer fibers of each toroidal element. During impact, the two cylinders experience relative motion but remain intact, that is, they do not deform plastically. The two cylinders transmit the impact forces into the toroidal elements of the helical coil and exert sufficient compressive forces on each toroidal element to force the elements to roll rather than slide between the two cylinders. This energy absorber, unlike the other types which rely on one-time unidirectional straining to failure, can be checked out even if used only as a one-time device. This device is relatively simple to manufacture. The critical factor is the establishment of the proper tolerances between the diameter of the helical wire working element and the annulus between the two tubes. The device operates in tension or compression, is relatively simple to reset, and has a negligible velocity and temperature sensitivity. An example of controlled tests on this device over a wide range of velocities and temperatures is its application to the interpanel crew escape system for the space shuttle.[2] The devices are used

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[2] B. Mazelsky, Certification of TOR-SHOK Cable Assembly Interpanel Crew Escape System, ARA Report No. 178, December 30, 1976.

on each interpanel to ensure proper deployment of the interpanel prior to emergency egress of both crewmen.

The aluminum alloy TOR-SHOK Energy Absorber manufactured by ARA, Inc., West Covina, CA, or an equivalent energy absorber, must meet the following specifications:

A. The attenuation force must be 1360 lb. with a maximum of $\pm$ 10% variation.

B. The energy absorber must work in tension and compression.

C. The energy absorber must be reusable to check loads for quality assurance.

D. The energy absorber must use the principle of a cyclic strain device.

E. The maximum outside diameter must be equal to or less than 1.375 inches.

F. The energy absorber must stroke a minimum of 8.38 inches when loaded in tension.

The wire used as the working element in the ARA, Inc. Energy Absorber is approximately .030 inch diameter; this diameter varies with the annular space available. Between 32 and 36 wraps of wire are used.

Following assembly, the energy absorber is sealed at both rod end bearings and at the faying area between the inner and outer tube assemblies, the sealing compound used is Part No. 3C408 B 1/2 of the Churchill Chemical Co., Los Angeles, CA. After sealing, the assembly receives one coat of zinc chromate primer and a finish coat of lusterless gray cellulose-nitrate lacquer.

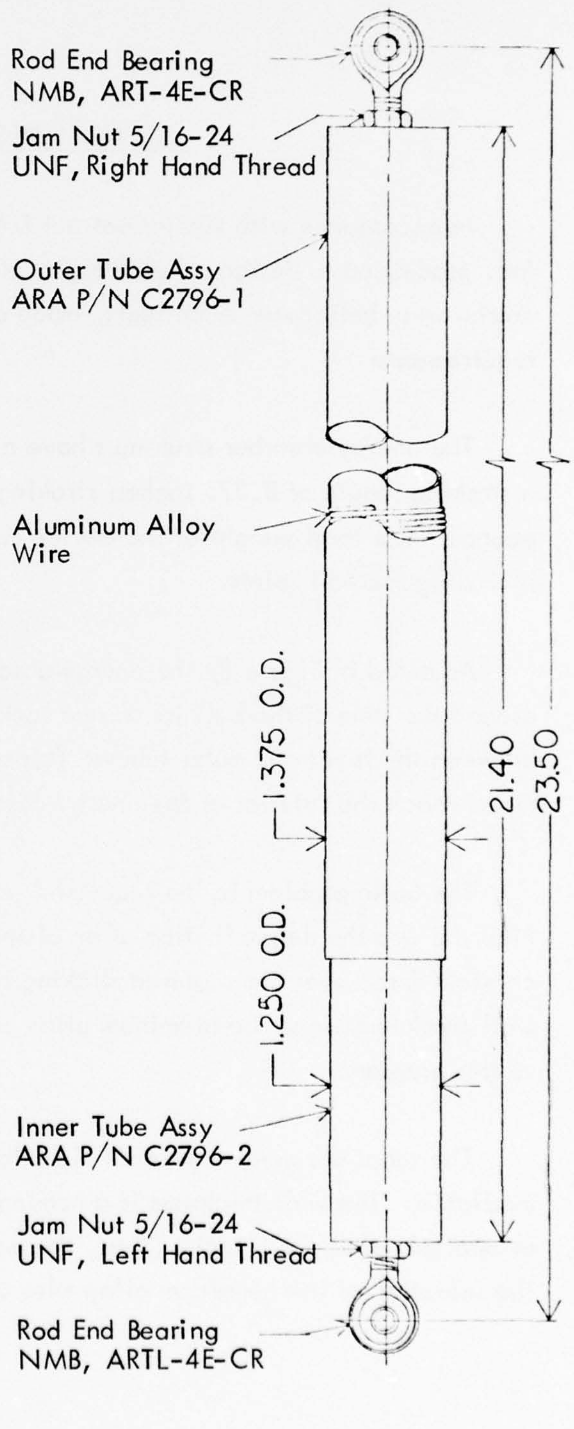

Figure 3. Aluminum Alloy TOR-SHOK.

GENERAL DESCRIPTION

In accordance with Army Contract DAAJ02-75-C-0015 requirements, ARA, Inc. proceeded to design a lightweight rolling helix energy-absorbing leg, for crashworthy helicopter troop seats, made of aluminum and which met the following requirements:

The energy absorber strut must have a maximum length of 21.40 inches with a stroking length of 8.375 inches; stroking shall occur at a limit load of 1360 pounds. The total weight of the device must not exceed nine (9) ounces, not including the ball joints.

As noted in Figure 3, the energy absorber is completely sealed at each end around the stem of the ball joints and locking nuts, as well as at the faying area between the inner and outer tubes. This sealing procedure assures that no contamimants reach the interior of the energy absorber.

The basic problem in the successful operation of the energy absorber shown in Figure 3 was the determination of an aluminum alloy wire capable of providing a constant force over the required stroking length. All the other parameters, such as wall thicknesses and the aluminum alloy of the tubing, were already known prior to this program.

The tubes are made from 6061-T6 alloy aluminum tubing, which is readily available. The wall thickness is a nominal .035 inch and requires a wire diameter of approximately .030 inch. Thus, the major portion of this investigation was the selection of the aluminum alloy wire capable of providing the required

stroking distances for the energy absorber. A typical application of an energy-absorbing leg for a troop seat is shown in Figure 4.[3]

[3] Reilly, Mason J., CRASHWORTHY TROOP SEAT INVESTIGATION, Boeing Vertol Company, USAAMRDL-TR-74-93, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, December 1974, AD A007090

Figure 4. Typical Troop Seat Utilizing Energy-Absorbing Legs.

TESTING FOR SELECTION OF VARIOUS ALUMINUM ALLOY WIRES

The aluminum alloy wires that were tested to ascertain adequate performance for the energy-absorbing helical coil were: 6061-H13, 2024-H13, 2024-T4, and 5056-H38. The tubing used for all the energy absorbers was alluminum alloy 6061-T6. The tubes were anodized in accordance with MIL-A-8625, Type 1. Each energy absorber was manufactured, assembled and tested identically for each of the helical coil wire types. Each device was stroked in tension statically on a Tinius-Olsen test machine. The results of the tests for each aluminum helical coil wire assembly are provided as follows:

1. Aluminum Alloy Wire 6061-H13

The initial breakout load was 1340 pounds of force. This load was maintained for approximately one (1) inch of stroke; beyond that point, the load steadily increased, so that after two (2) inches of stroke the load had climbed to 3000 pounds and the test was stopped. X-ray examination of the energy absorber revealed numerous broken wires and showed that many portions of the broken wire sections had overlapped themselves, causing the large increase in stroking force. This test indicated that the aluminum alloy wire 6061-H13 was considered unacceptable because only one (1) inch of constant force stroke could be maintained. Although cyclic straining of the wire exists during its assembly, it should be noted that one (1) inch of usable stroke represents approximately ten (10) strain cycles on the helical coil wire.

2. Aluminum Alloy Wire 2024-H13

The initial breakout load was 1390 pounds of force. This load was relatively constant for approximately three (3) inches of stroke. Beyond this point, the load steadily increased until it reached 2800 pounds of force, which occurred at five (5) inches of stroking distance. At this point, the test was stopped. X-ray

examination of the device revealed the same condition of the helical wire that was noted for the previous test. This aluminum alloy wire was also considered unacceptable. Only three (3) inches of constant force stroke could be maintained. This stroking distance represents approximately thirty (30) strain cycles on the helical coil wire, which does not include the cycling required to assemble the device.

3. Aluminum Alloy Wire 2024-T4

The initial breakout load was 1360 pounds of force. This load was relatively constant for approximately seven (7) inches of stroke. Beyond this point, and up to the last 1-1/2 inches of stroke, the load steadily decreased and reached a final value of 1100 pounds of force at 8-1/2 inches of stroke. This assembly was pulled apart and visual examination indicated numerous broken wires in the helical coil. This aluminum alloy wire was also considered unacceptable due to its inadequate fatigue life. Only seven (7) inches of constant force could be maintained. This stroking distance, neglecting the initial strain cycles on the helical coil wire.

4. Aluminum Alloy Wire 5056-H38

The initial breakout load was 1360 pounds of force. This load was relatively constant throughout the entire 8-1/2 inches of stroke, except for a slight reduction of thirty (30) pounds in force which occurred at the very end of the stroke. This device was disassembled and visual examination revealed no defects in the wire or the tubing. Detailed examination of the helical coil indicated no visual signs of fatigue, cracks, or breaks.

Based on these tests, the 5056-H38 aluminum alloy wire was selected for the helical coil energy-absorbing element in the additional test assemblies described in the next section. The results of the preliminary tests conducted herein indicate the adequacy of the 5056-H38 aluminum alloy wire to provide, at a minimum, a stroke of 8-1/2 inches.

STATIC TESTING OF THE ALUMINUM ENERGY ABSORBER

Using the combination of anodized aluminum alloy 6061-T6 tubing and aluminum alloy 5056-H38 wire, nine (9) energy absorbers were manufactured in accordance with the requirements listed in Figure 3. Three (3) of the energy absorbers were statically tested by ARA, Inc. Two (2) energy absorbers were subjected to environmental testing in accordance with MIL-STD-810B. One (1) of the two (2) environmentally tested units (Serial No. 102) was also statically tested at ARA, Inc.; the other unit (Serial No. 104) was submitted to and tested by the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory. In addition, three units were also supplied to the Eustis Directorate for further test evaluation.

During the assembly of all of the energy absorbers, the force to stroke the tubes was monitored continuously. Prior to final welding of the end cap on the larger diameter tube, each device was stroked approximately 1/2 inch to verify the load. In addition, each device was X-rayed to verify the condition and location of the helical coil wire with respect to the tubes. No defects were found on any of the devices fabricated. The three (3) energy absorbers that were not subjected to the environmental testing were statically tested on a Tinius-Olsen machine to determine the force-stroke characteristics. The rate of load application on the Tinius-Olsen machine was four (4) inches per minute. The results of these static tests are summarized in Figure 5 and are described herein. The serial numbers of the three (3) energy absorbers that were not subjected to the environmental tests are Serial No. 101, Serial No. 103, and Serial No. 109.

Upon completion of the static testing, each energy absorber was disassembled and no defects were noted in the wire or in the tubing. Detailed examination of

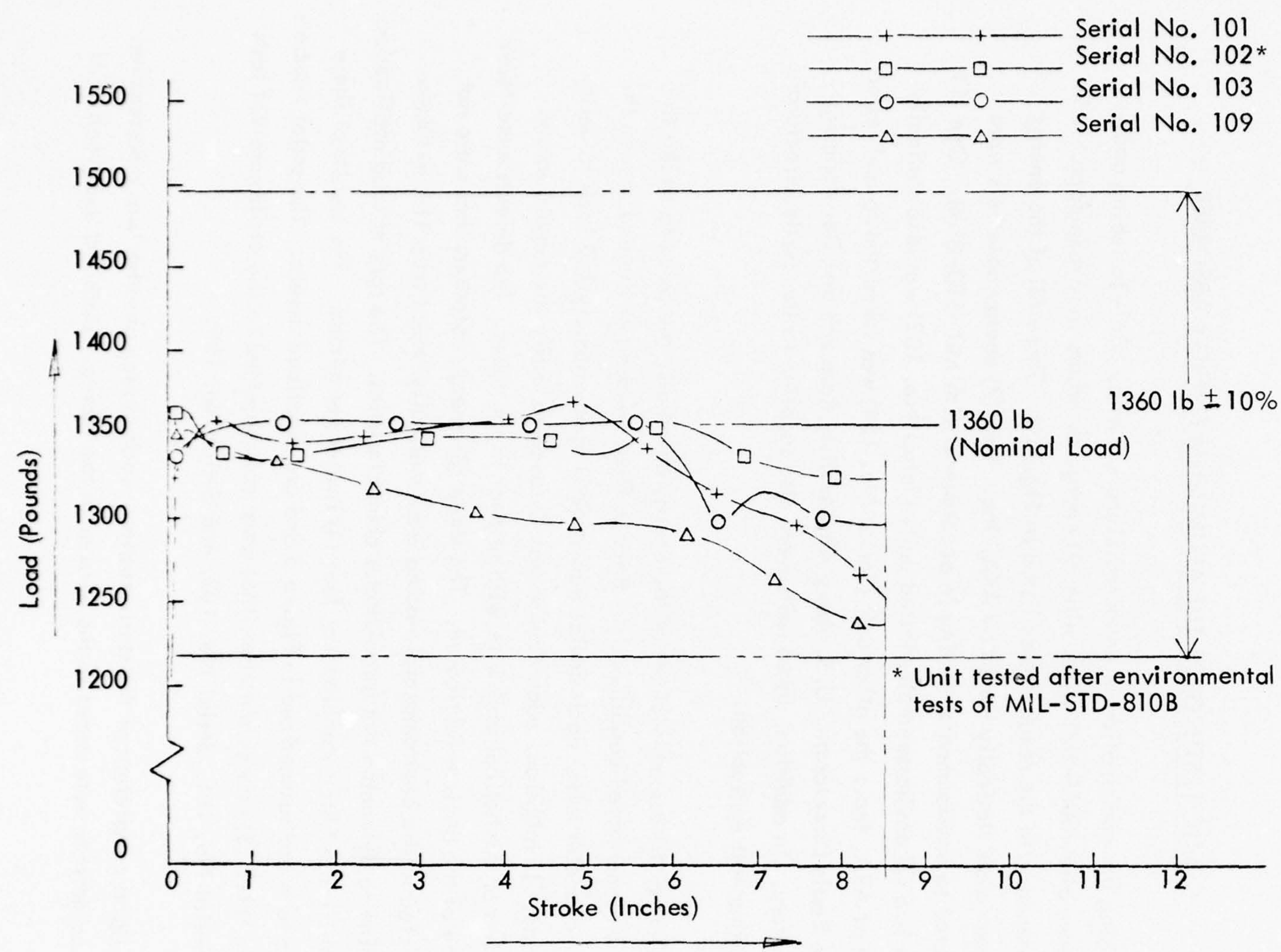

Figure 5. Load-Stroke of Aluminum TOR-SHOK (Displacement Rate: 4inches/minute).

the helical coil indicated that there were no fractures, breaks or imperfections in the length of the helical coil wire.

1. Serial No. 101

The test on the Tinius-Olsen revealed that the initial breakout force was 1320 pounds. This force was maintained for 7-1/2 inches of stroke and during the last 1-1/2 inches, the load reduced slightly by approximately sixty (60) pounds to a load value of 1260 pounds.

2. Serial No. 103

The results of the static test are provided in Figure 5; the initial breakout force was 1340 pounds. For approximately 5-1/2 inches of stroke the force level was 1360 pounds, which corresponds to the nominal design load. For the remaining three (3) inches, the load decreased slightly to a final value of approximately 1300 pounds.

3. Serial No. 109

The device was tested in a similar fashion, and the initial breakout force was approximately 1360 pounds. This force was reduced slightly as stroking occurred and at five (5) inches to 8-1/2 inches the load decreased still further to 1240 pounds, which occurred at the end of the stroking distance of 8-1/2 inches.

4. As noted previously, two (2) energy absorbers were subjected to the environmental test of MIL-STD-810B. Serial No. 104 was delivered to the Eustis Directorate, USAAMRDL, for testing of this energy absorber. Serial No. 102 was statically tested at ARA, Inc., and the results of this test are summarized as follows:

Serial No. 102

Prior to detailed X-ray inspection, the energy absorber was visually

inspected externally to determine the condition of the device. Detailed examination indicated that there were no surface defects on the paint and the seals were completely intact. An X-ray inspection confirmed that no internal defects existed. The helical coil wire remained intact and its location was identical to that measured prior to the environmental tests. Based on this inspection, it appeared that the environmental tests had no effect on the condition of the energy absorber. However, to further establish its condition, a static test to determine the load-stroke curve was conducted. The results of this static test for Serial No. 102 are summarized in Figure 5 for comparison with the other three (3) energy absorbers that were not environmentally tested. For Serial No. 102, the initial breakout force was approximately 1380 pounds. After the breakout force, the energy absorber varied at a load level of approximately 1350 pounds for a stroking distance up to approximately seven (7) inches. From that point on to the final stroking distance of 8-1/2 inches, there was a slight decay in the load of approximately fifty (50) pounds during the last portion of the stroke. Upon completion of the static test, the unit was disassembled, and as noted for the previous devices that were tested, there were no defects in the tube or the helical coil wire.

Detailed examination of the data presented in Figure 5 indicates that the aluminum energy absorber with the aluminum alloy 5056-H38 wire provides a relatively constant nominal load of 1360 pounds for a stroke of 8-1/2 inches. This device can be manufactured within a load tolerance of $\pm$ 10 percent. The results of these tests also indicate that the environmental conditions as defined by MIL-STD-810B have no measurable effect on the performance of the energy absorber. The only deviation of the force-stroke curves noted throughout the entire static test program was the slight decay of the force level as the energy absorber was extended in length to its maximum limits. This slight decay is attributed to the fact that the energy absorber was assembled with the two (2) tubes initially in their maximum extended position. Thus, during assembly, the wire had subjected both tubes to a

stress level which slightly yielded the tubes, resulting in a reduction of compression force on the wire when the tubes were once again in the same extended positions during the stroking condition. This slight decay in force level can be eliminated by loading the energy absorber from the rearward position, which would, however, require the welding of the end cap on the larger diameter tube after the loading process is completed. In order to provide adequate strength for the end cap when welded in the non-heat treated condition, 5086-H38 aluminum alloy should be used for the end cap. This material has sufficient strength characteristics to retain structural integrity without the need of heat treating the tube and the end cap after welding. If the end cap is welded after the wire has been assembled in the tubes, the assembly cannot be heat treated without destroying the load-stroke characteristics of the device.

All of the static testing conducted at ARA, Inc. was witnessed by United States Government representatives from the Defense Contract Administrative Services Region. A description of the environmental tests, and the results, are provided in Appendix A. These tests were also witnessed and verified by Quality Representatives from the Defense Contract Administrative Services Region.

The verification of a design by submission to MIL-STD-810B environmental tests may not be adequate with respect to the vibration environment. The vibration test required by this standard is a test for a resonance search, frequency cycling (only three (3) hours), and a resonant dwell (only three (3) minutes for each of four (4) frequencies). An assessment of the ability of the rolling helix strut to perform its intended function after being subjected to environmental conditions, including lengthy exposure (5000 or more hours) to in-flight loads and vibrations, should be ascertained. This determination can best be accomplished by installing those devices in operational aircraft, and measuring the load-stroke characteristics after being exposed to a number of flight hours. Such an investigation is beyond the scope of this program.

Three (3) of the energy absorbers delivered to the Eustis Directorate were dynamically tested. Two (2) of the devices (Serial Numbers 106 and 107), which had not been subjected to MIL-STD-810B environmental testing, were installed in the crashworthy troop seat shown in Figure 4, which, in turn, was installed on a vibration table. A sandbag weighing 150 pounds was strapped in the seat, and the seat was subjected to a $\pm$ 0.5G, 19.1-Hz sinusoidal vibratory pulse for 832 hours. This vibration environment was selected as being a representative helicopter cabin inflight vibration environment. After 832 hours, both of these energy absorbers and energy absorber (Serial Number 104) were stroked in tension at a head rate of 5.2 ft/sec. The resulting load-stroke curves for the three devices are shown in Figure 6. The three energy absorbers behaved similarly. However, the load-stroke curves for these devices differed in three (3) respects from those shown in Figure 5:

1. A 'spike' occurred at the initiation of stroking.
2. The stroking load after this spike was lower than that shown in Figure 5, and
3. The stroking load after the spike was more constant than the stroking loads shown in Figure 5.

The spike, which is shown for each of the attenuators in Figure 6, does exist but did not show up due to the inertia of the recording system used in measuring the load-stroke static test curves of Figure 5. The spike is of a very short duration and is due to the preset of the wire. This initial deformation of the wire quickly disappears when stroking occurs. The variation of the stroking loads after the spike between the units shown in Figures 5 and 6 are very small and are due to manufacturing variations. For example, the units in Figure 6 were made after the units of Figure 5 were fabricated. The slight decay of the load with stroke is due to the minute yielding of the tubes during the loading process. This slight decay

can be eliminated by loading the tubes from the rearward position so that during stroking virgin tube material is used to cause the rolling forces on the helical wire.

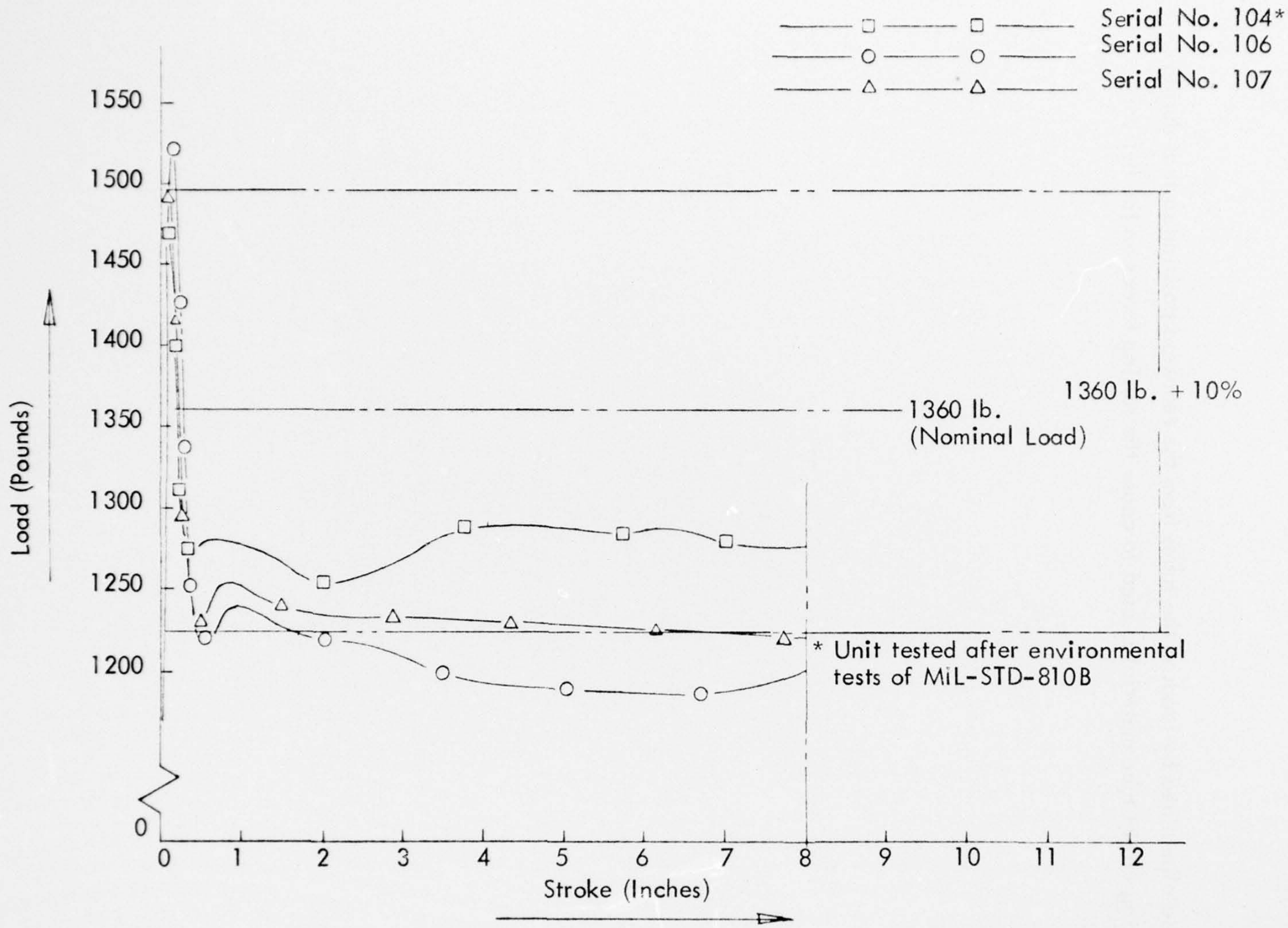

Figure 6. Load-Stroke of Aluminum TOR-SHOK (Displacement Rate: 5.2 ft/sec.).

COMPARISON OF SPECIFIC ENERGY ABSORPTION FOR ALUMINUM AND STEEL ROLLING-HELIX ENERGY ABSORBERS

One of the primary purposes of this study was to establish the feasibility of a light and efficient energy-absorbing strut for a crashworthy troop seat. In order to define more specifically the efficiency of the strut, a comparison was made of the SEA capabilities of the aluminum strut and the value that would be obtained if the strut was made entirely of steel instead of aluminum. As noted previously, if the load requirements of the energy absorber are relatively low, then the strength-to-weight ratio of aluminum tubing, such as 6061-T6, may be adequate. However, when the load requirements of the energy absorber are high, as would be the case for an armored crew seat, then a higher strength-to-weight ratio for the tubing would be required, necessitating the use of materials such as 4130 steel, heat treated to a tensile strength of approximately 180,000 pounds per square inch. For this case, the force level of the energy absorber should be increased from a troop seat value of 1360 pounds to approximately 3000 pounds, which is a representative force level for the rolling helix struts used on the armored crashworthy crew seat presently installed on the Bell Helicopter Textron Model 214A Aircraft.

In order to make a meaningful comparison of the SEA for the aluminum and steel struts, the following assumptions were made:

1. The stroking force of the aluminum rolling helix strut is 1360 pounds, while the stroking force for the steel rolling helix strut is 3000 pounds.

2. The length, diameter, and wall thickness of the aluminum and steel tubing should be identical, in order to establish the same plastic strain on the helical coil wire for both the aluminum and steel wire.

3. For calculating the SEA values, the configuration described in Figure 3 was used.

The first comparison was made for the working elements only; that is, the SEA was computed for the helical coil 5056-H38 aluminum alloy and stainless steel 300 series wires. In order to establish an equitable stroking distance, a value of ten (10) inches was used for both cases. For the aluminum wire, approximately 32 coils are required to obtain a stroking force of 1360 pounds, while for the stainless steel wire, thirty (30) coils are required to obtain a stroking force of 3000 pounds.

The SEA for the aluminum wire working elements was calculated to be:

$$(SEA)_{\text{Al (wires only)}} = 125{,}089\ \frac{\text{foot-pounds}}{\text{pound}}$$

The SEA for the stainless steel wire working elements was calculated to be:

$$(SEA)_{\text{Steel (wires only)}} = 94{,}051\ \frac{\text{foot-pounds}}{\text{pound}}$$

Next, the SEA for the total energy-absorbing struts were calculated, based on the assumptions previously noted.

The SEA for the aluminum strut was calculated to be:

$$(SEA)_{\text{Al Strut}} = 1{,}983\ \frac{\text{foot-pounds}}{\text{pound}}$$

The SEA for the steel strut was calculated to be:

$$(SEA)_{\text{Steel Strut}} = 1{,}543 \frac{\text{foot-pounds}}{\text{pound}}$$

Comparison of the calculations indicate that for the configurations considered, the aluminum strut is superior, even though the force used for the steel configuration was 3000 pounds. If the steel strut force was 1360 pounds, as would be the case for the troop seat application, the comparison with the aluminum strut would be even more dramatic. However, as noted previously, when higher force levels are required, such as on the armored crew seats, the strength-to-weight ratio of the 6061-T6 aluminum tubing would be inadequate, and the steel tubing would be required.

Additional research conducted by ARA, Inc. on the steel strut has indicated that the tubing diameters shown in Figure 3 for the aluminum configuration may not be optimum for the steel strut to obtain a maximum SEA value. A new steel strut has been fabricated and tested using 1-1/8-inch-diameter material for the outer tube and 1-inch diameter material for the inner tube. This configuration has reduced the weight of the device, and has required less coils to obtain a load of 3000 pounds, resulting in more space for stroking distance, based on a fixed length of tubing.

COSTS

One of the requirements of this study was to provide a cost estimate of the aluminum rolling helix strut in a quantity of 1000. It was estimated that based on a normal manufacturing burden rate, the aluminum strut could be built for approximately $100. This unit would also include the ball joints at each end and the jam nuts. It should be noted that this price is predicated on material and labor costs using 1976 dollars. The prices are contingent on the fact that the strut will be made in accordance with Figure 3. If the more expensive end cap using 5086-H38 series aluminum is used, and a stopping ring is welded on the outer tube (at the opposite end of the end cap), the price of $100 per unit would be increased approximately ten (10) percent. The requirement for these additional features would depend to a large extent on the acceptability of the load variation tolerances, as well as on the particular application of the strut to the crashworthy troop seat.

CONCLUSIONS AND RECOMMENDATIONS

This report covers a feasibility investigation of selecting aluminum alloy wires required to manufacture an aluminum strut for use in crashworthy troop seats. This investigation indicated that the most compatible aluminum wire to be used for the 6061-T6 aluminum tubing is the 5056-H38 series aluminum wire. By properly anodizing and sealing the aluminum tubing, the strut, after being subjected to the environmental tests as dictated by MIL-STD-810 B, performed the same as those struts which were not subjected to the environmental tests. As a result of this study program, the objective of determining the feasibility of the aluminum strut was clearly established.

The specific energy absorption of the aluminum strut is very competitive with the steel strut as used in crew crashworthy seats. Since the troop seats require longer struts at much lower force levels than the crew seats, the aluminum strut is recommended for the troop seat since its efficiency would be much greater than the steel strut. For shorter length struts at high loads, the strength-to-weight of the steel tubes is structurally more efficient than the aluminum tubing.

The cost of the aluminum struts will vary due to detailed methods of fabrication and application to the particular troop seat detail design. Based on 1976 dollars, the price of the unit (in quantities of 1000) would be approximately $100 which would include all end fittings, sealants, coatings, paint, etc., and quality control procedures such as X-ray documentation and load-stroke curves.

The results of the AMRDL vibration tests indicate that the units tested did not vary appreciably in load stroke characteristics from those that were or were not exposed to the environmental tests of MIL-STD-810 B.

The major difference in load-stroke curve measurements between the static and dynamic tests of the units were associated with an initial spike. This spike does exist and was recorded in the dynamic tests; the inertia of the recording system in the static tests prevented the accurate measurement of the spike.

The use of attenuators in crashworthy troop seats presents a new set of components that cannot be evaluated for reliability and maintainability by only meeting the requirements of MIL-STD-810. Additional service testing must be accomplished together with developing service manuals to ensure proper functioning of the attenuators during a crash.

APPENDIX A

QUALIFICATION TEST REPORT ON TOR-SHOKS

Part Number C-2795

Two (2) struts, Part Number C-2795, Serial Numbers 102 and 104, were subjected to the following Qualification Tests performed in accordance with Military Standard 810B:

Test Title	Ref. Method MIL-STD-810B
High-Temperature Test	501, Procedures I and II
Low-Temperature Test	502
Humidity Test	507, Procedure II
Salt Fog Test	509
Dust Test	510
Vibration Test	514.1, Procedure 1

High-Temperature Test

Procedure 1. The specimens were installed in the temperature chamber. The internal temperature was raised to 77°C (170°F) and held for 48 hours.

The test chamber temperature was reduced to 51.7°C (125°F) and maintained for 1.5 hours.

Procedure II. The specimens were installed in the temperature chamber, and the temperature was increased to 49°C (120°F) and maintained for six (6) hours.

The temperature was then raised to 68°C (154°F) and maintained for five (5) hours.

The temperature was then reduced to 49°C (120°F) within one (1) hour.

The preceding three (3) steps were repeated two (2) more times, for a total of three (3) 12-hour cycles.

Chamber temperature was stabilized at 52°C (125°F). Then the specimens were reduced to ambient temperature and inspected for damage.

Results: There was no visual evidence of damage to either specimen as a result of the high-temperature test.

Low-Temperature Test

The specimens were installed in the temperature chamber. The internal chamber temperature was reduced to -51°C (-60°F) and held for one (1) hour.

The chamber temperature was then raised to -34°C (-40°F) and held for 1.5 hours.

Then the specimens were returned to ambient temperatures and inspected for damage.

Results: There was no visual evidence of deformation or damage to either specimen as a result of the low-temperature test.

Humidity Test

The specimens were replaced in a humidity chamber and subjected to five (5) continuous 48-hour cycles in accordance with Figure 507-2 of MIL-STD-810B.

Results: There was no visual evidence of deformation or damage to either specimen.

Salt Fog Test

The specimens were installed in the test chamber and subjected to 48 hours of salt fog exposure with a 5% salt solution.

Chamber temperature was maintained at 95°F. Solution pH was 6.8.

Results: There was no visual evidence of corrosion of the specimens.

Dust Test

The specimens were suspended in the dust chamber, and the internal temperature was set for 23°C (73°F) with a relative humidity of less than 22%.

Air velocity was set for 1750 $\pm$ 250 fpm with a dust concentration of 0.3 $\pm$ 0.2 gram per cubic foot. These conditions were maintained for six (6) hours.

At the end of the 6-hour period, the dust feed was stopped and the air velocity was reduced to 300 $\pm$ 200 fpm. Temperature was increased to 63°C (145°F) and relative humidity lowered to 10%. These conditions were maintained overnight.

The air velocity was then increased to 1750 fpm with a dust concentration of 0.3 gram per cubic foot. Temperature was held at 63°C (145°F). These conditions were maintained for six (6) hours.

The chamber was reduced to ambient temperature. Excessive dust was brushed from the specimens.

Results: There was no visual evidence of damage to either specimen.

Vibration Test

The specimens were installed on an electrodynamic shaker by their normal mounting means. They were subjected to the following vibration tests in each of the three (3) mutually perpendicular axes.

Resonant Search. The specimens were subjected to a logarithmic sweep of approximately 0.8 octave per minute from 5 to 500 Hz as follows:

Frequency (Hz)	Vibration Level
5 to 20	0.1 inch double amplitude
20 to 33	2.0 g peak
33 to 52	0.036 inch double amplitude
52 to 500	5.0 g peak

Resonant Dwell. The resonant frequencies of the specimens were selected from the search X-Y plots. The most severe resonant points were selected (up to four), and a 30-minute dwell was performed at each resonance in each axis.

Frequency Cycling. The specimens were subjected to logarithmic frequency cycling from 5 to 500 Hz. at approximately 0.8 octave per minute. The sweep rate was such that the total cycling was accomplished in 15 minutes. The total vibration time in each axis was three (3) hours. This includes the search, dwell, and cycling times.

Results: There was no visual evidence of damage or deformation to either specimen.